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# The Fabrication of Deuterium Loaded Fiber Bragg Grating and Its Spectral Characteristics in Thermal Annealing

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## ABSTRACT

Previous results showed that the non-reversible(hysteresis loop) of Bragg wave length shifting in thermal cycling of the Fiber Bragg Grating which is a high germanium doped optical fiber and high pressure hydrogen loaded was due to the diffusion out of the H<sub>2</sub> residue in thermal annealing. In addition, the O-H absorption peak (1.38 $\mu$ m) causes signal attenuation and stability problem in FBG applications. We demonstrated the fabrication of the D<sub>2</sub> loaded FBG with high stability of Bragg wave length in thermal annealing at temperature up to 250 °C. The spectrum characteristics of the D<sub>2</sub> loaded FBG compare to the H<sub>2</sub> loaded FBG is presented. In general,  $\Delta \lambda_B$  of the D<sub>2</sub> loaded FBG is narrower than H<sub>2</sub> loaded, and  $\lambda_B$  of the D<sub>2</sub> loaded FBG is more stable than H<sub>2</sub> loaded in thermal annealing. A model base on the UV photo-induced index change in FBG core with D<sub>2</sub> and H<sub>2</sub> loaded to explain the spectrum characteristics between D<sub>2</sub> and H<sub>2</sub> loaded FBG is discussed.

Keywords: Fiber Bragg grating, deuterium loading

## 1. INTRODUCTION

Fiber Bragg grating has known to be the most advanced passive component for applications in fiber optic communication and sensor systems because of its low insertion loss, narrow band pass, and the flexibility of manipulating desired spectral characteristics [1-5]. FBG can be easily tailored by induced index change, grating length, chirping, and apodization, so that the desired spectral characteristics, such as filtering wavelength, reflectivity, and band-width can be achieved. In general, a FBG device is used to convert the variation of temperature or strain of the tested environment. The Bragg wavelength shifting then can be measured by interrogating, or by interferometric approach [6-9].

Thus, the performance of the fiber-optic sensing system is significantly affected by the spectrum stability of the FBG components.

Various approaches to fabricate the FBG have been demonstrated [10-19]. High pressure H<sub>2</sub> loading is one of the well known process to enhance the photo-sensitivity of the high germanium doped fiber by deep UV writing (248 nm). The hydrogen loading process is low cost and reproducible. Previous report showed that the hydrogen loaded FBG has an intrinsic absorption peak at 1.38  $\mu$ m by the O-H bond [20-21]. This O-H absorption might cause intrinsic problem to fiber optic communication system where a 1.3  $\mu$ m laser source is usually used. In addition, the residue of H<sub>2</sub> cause the drifting of the effective index change of the fiber, which in turn can affect the reflectivity and Bragg wavelength of the FBG. Although, this drift can be eliminated by cycles of post annealing, but will decrease the reflectivity of the FBG. It is suggested that the hysteresis of Bragg wavelength shifting is contribute to the diffusion out of the H<sub>2</sub> residue in thermal annealing.

In this report, we demonstrate the fabrication of the FBG using high pressure D<sub>2</sub> loading, and shows the improvement of the spectral characteristics of the FBG.

## 2. EXPERIMENTS

Samples of high germanium doped single mode fiber were kept in 1/4 " stainless steel (SS304) tubing pressurized at 1500 psi of H<sub>2</sub>/D<sub>2</sub> for days until the saturation was reached. The concentration of H<sub>2</sub> in the fiber can be monitored by the

H<sub>2</sub>O absorption peak at 1.24  $\mu\text{m}$ , but the detection of the D<sub>2</sub> related absorption peaks is beyond the spectrum range of the optical spectrum analyzer (HP 70951B) in use. The saturation of the D<sub>2</sub> is estimated by the diffusion coefficient of D<sub>2</sub> which is  $1/\sqrt{2}$  to H<sub>2</sub>.

Figure 1 shows the FBG deep UV exposure system. A KrF excimer laser at 248 nm is used to induce the index change of the Ge-doped dispersion sifted fiber, a phase mask with 1.0780  $\mu\text{m}$  grating period is used to generate the grating on the fiber core, and the HP 70951B optical spectrum analysis system with a white light out put is used to record the real time transmission of the FBG during UV exposure at 60 mJ/cm<sup>2</sup> fluence and 5 Hz pulse rate. Figure 2 shows the transmission spectrum with Bragg wavelength at 1.55 nm of the FBG with D<sub>2</sub> and H<sub>2</sub> loaded. It reveals that the absorption peak of O-H (1.38 nm) appearing beside the 1.55 nm of Bragg wavelength, but is avoided in the spectrum of D<sub>2</sub> loaded FBG.

### 3.RESULTS AND DISCUSSION

Figure 3 shows the transmission spectrum of the D<sub>2</sub> loaded and H<sub>2</sub> loaded FBG. In general, the spectrum of H<sub>2</sub> loaded FBG is wider than the D<sub>2</sub> loaded FBG, and significantly, a side lobe next to the Bragg reflection peak.

In characterizing the FBG spectrum variation in thermal annealing, the FBG sample was annealed on a hot plat which was kept at a set temperature for a period of time to record the spectrum, then repeat the same process at another higher temperature up to 200 °C. Figure 4,5 are the spectrum variation of H<sub>2</sub> / D<sub>2</sub> loaded FBG in thermal annealing. It is clearly shown that the D<sub>2</sub> loaded FBG has better spectrum stability than H<sub>2</sub> loaded FBG. The Bragg reflection spectrum of the D<sub>2</sub> loaded FBG is almost reversible with temperature, but there is a serious hysteresis loop in the spectrum of the H<sub>2</sub> loaded FBG due to thermal annealing.

It is the fact that the residue of the D<sub>2</sub> or H<sub>2</sub> can vary the effective index  $n_{\text{eff}}$  of the fiber core. It is suggested that the non-reversible spectral histogram of the H<sub>2</sub> loaded FBG in thermal annealing might be due to the over loading of H<sub>2</sub>, in which decrease of concentration of H<sub>2</sub> in fiber core can cause significant drifting of the effective index. If this is the case, it might suggest that the non-reversible variation of the H<sub>2</sub> loaded FBG spectrum in thermal annealing could be improved by reducing the concentration of H<sub>2</sub> in the fiber core to some threshold level. Also, the diffusion coefficient of D<sub>2</sub> or H<sub>2</sub> might be another factor to affect the stability of the FBG spectrum in which the diffusion of D<sub>2</sub> is slower because of its heavier molecular weight, and refers that spectral stability of the D<sub>2</sub> loaded FBG is better than H<sub>2</sub> loaded FBG.

### 4.CONCLUSIONS

We demonstrated the improvement of the FGB spectral stability by using D<sub>2</sub> loading. The identification of the mechanism responsible for the non-reversible spectrum variation of H<sub>2</sub> loaded FBG in thermal annealing, and the difference of the spectrum characteristics between H<sub>2</sub> loaded and D<sub>2</sub> loaded FBG is not clear. Further experiments to quantitatively measure the variation of the FBG spectrum characteristics parameters in thermal annealing with respect to the concentration of D<sub>2</sub>/ H<sub>2</sub> in the fiber core is needed to explore the mechanism of the spectrum variation. Further exploration of the mechanism which responsible to the spectrum characteristics is important to achieve stable FBG devices in practical applications.

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### REFERENCES

1. K.O. Hill, Y. Fujii, D.C. Johson, and Kawasaki, Appl. Phys, Lett, 32,647(1987)
2. M. Kawasaki, M. Yasu, and T. Edahiro, Electron. Lett.,19,583(1983)
3. Barnoski, M. K., and S. M. Jensen, Fiber waveguides: a novel technique for investigating attenuation characteristics. *Appl. Optics*, Vol. 15, 1976, p. 2112.
4. D. C. Lee, J. J. Lee & S. J. Yun, The mechanical characteristics of smart composite structures with embedded optical fiber sensors, *Composite Structures*, 32 (1995) 39 - 50.
5. Marten de Vries, Vikram Bhatia, Tiffanie D'Alberto, Vivek Arya and Richard O. Claus, Photoinduced grating-based optical fiber sensors for structural analysis and control, *Engineering Structure*, Vol. 20, No. 3, 1998, p.205 - 210.
6. H. Singh and J. S. Sirkis, Temperature and Strain Measurement by combining ILFE and Bragg Grating Optical Fiber Sensors, *Experimental Mechanics*, Vol. 37, No. 4, December 1997, p415.

7. Takamasa Suzuki, Takao Okada, Osami Sasaki, Takeo Maruyama, Real-time vibration measurement using a feedback type of laser diode interferometer with an optical fiber, *Optical Engineering*, Vol. 36, No. 9, September 1997, p2497.
8. Alan D. Kersey, Michael A. Davis, Heather J. Patrick, Michel LeBlance, K. P. Koo, Member, IEEE, C. G. Askins, M. A. Putnam, and E. Joseph Friebele, Fiber Grating Sensors, *Journal of Lightwave Technology*, Vol. 15, No. 8, August 1997, p1442.
9. A. Yariv, IEEE, *J. Quantum Electron.* QE-9,919(1973)
10. D.K.W. Lam and B.K. Garside, *Applied Optics*, Vol. 20, No.3, 440(1981)
11. Culshaw, B., *Optical Fiber Sensing and Signal Processing*. Peter Peregrinus, 1984.
12. Meltz, G., W.W. Morey, and W. H. Glenn. Formation of Bragg gratings in optical fiber by a transverse holographic method. *Optics Lett.*, Vol. 14, 1989, p. 823.
13. Hill, K. O., B. Malo, F. Bilodeau, D.C. Johnson, and J. Albert. Bragg gratings fabricated in photosensitive monomode optical fiber by UV exposure through a phase mask. *Appl. Phy. Lett.*, Vol. 62, 1993, p. 1035.
14. Morey, W. W., J. R. Dunphy and G. Meltz. Multiplexed fiber Bragg grating sensors. *Proc. Distributed and Multiplexed Fiber Optic Sensors, SPIE*, Vol. 1586, 1991, p. 216.
15. Askins, G. C., M. A. Putman, G. M. Willjams, and E. J. Friebele. Stepped-wavelength optical fiber Bragg grating arrays fabricated in line on a draw tower. *Optics Lett.*, Vol. 19, 1994, p. 147.
16. K. W. Lam and B. K. Garside, Characterization of single-mode optical fiber filters, *Applied Optics*, Vol. 20, No. 3, 1 February 1981, p440.
17. G. Meltz, W. W. Morey, and W. H. Glenn, Formation of Bragg gratings in optical fibers by a transverse holographic method, *Optical Letters*, Vol. 14, No. 15, August 1, 1989, p823.
18. Robert Fedosejevs and M. J. Brett, Direct formation of grating structures on silicon using KrF laser radiation, *Applied Optics*, Vol. 28, No.10, 15 May 1989, p 1877.
19. J. P. Spallas, A. M. Hawryluk, and D. R. Kania, Field emitter array mask patterning using laser interference lithography, *J. Vac. Sci. Technol.*, B 13 (5), Sep/Oct 1995, p1973.
20. C.L. Liou, L.A. Wang, M.C. Shih, and T.J. Chuang, "Characteristics of hydrogenated fiber Bragg gratings", *Appl. Phys. A* 64, 191(1997)
21. Gang-Chih Lin, Likarn Wang, C.C. Yang, M.C. Shih, and T.J. Chuang, "Thermal Performance of Metal-Clad Fiber Bragg Grating Sensors", *IEEE Photonics Technology Letters*, Vol. 10, No. 3, 406(1998)

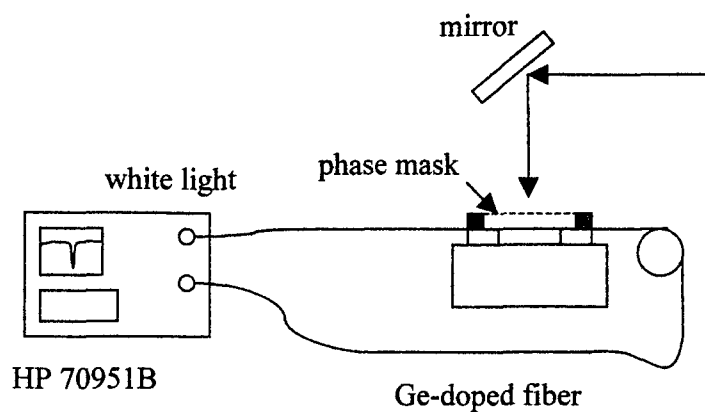
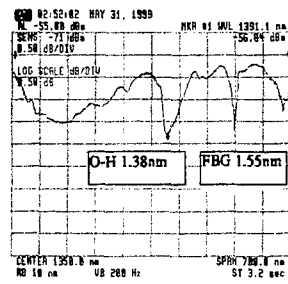
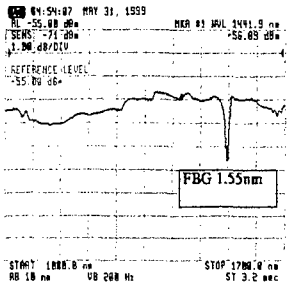


Figure 1. FBG deep UV exposure system. A KrF excimer laser at 248 nm is used to induce the index change of the Ge-doped dispersion sifted fiber, a phase mask with 1.0780  $\mu\text{m}$  grating period is used to generate the grating on the fiber core, and the HP 70951B optical spectrum analysis system with a white light out put is used to record the real time transmission of the FBG during UV exposure at 60  $\text{mJ}/\text{cm}^2$  fluence and 5 Hz pulse rate.

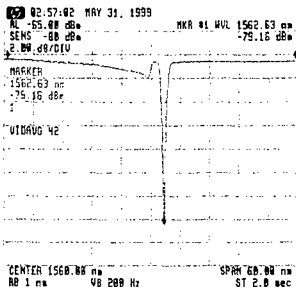


Transmission spectra of the H2 loaded FBG

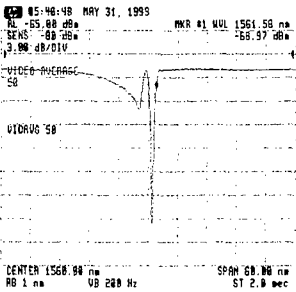


Transmission Spectra of the D2 loaded FBG

Figure 2. The transmission spectrum with Bragg wavelength at 1.55 nm of the FBG with D<sub>2</sub> and H<sub>2</sub> loaded. It reveals that the absorption peak of O-H (1.38 nm) appearing beside the 1.55 nm of Bragg wavelength(upper ), but is avoided in the spectrum of D<sub>2</sub> loaded FBG(below).

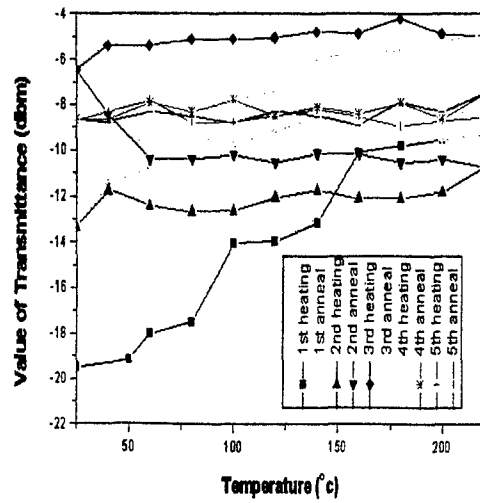


Transmission spectra of the D2 loaded FBG

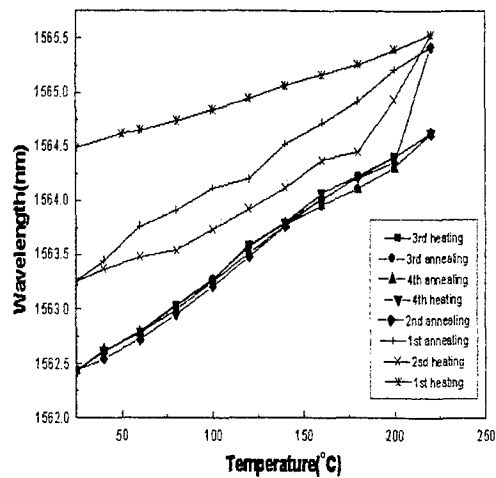


Transmission spectra of the H2 loaded FBG

Figure 3. The transmission spectrum of the D<sub>2</sub> loaded and H<sub>2</sub> loaded FBG. The spectrum of H<sub>2</sub> loaded FBG is wider than the D<sub>2</sub> loaded FBG, and significantly, a side lobe next to the Bragg reflection peak.



**Hysteresis of transmission of the H2 loaded FBG in thermal annealing**



**Hysteresis of wave length shifting of the H2 loaded FBG in thermal annealing**

Figure 4, The spectrum variation of H<sub>2</sub> loaded FBG in thermal annealing. It is clearly shown that there exists a non-reversible spectrum(hysteresis loop) variation in thermal annealing.

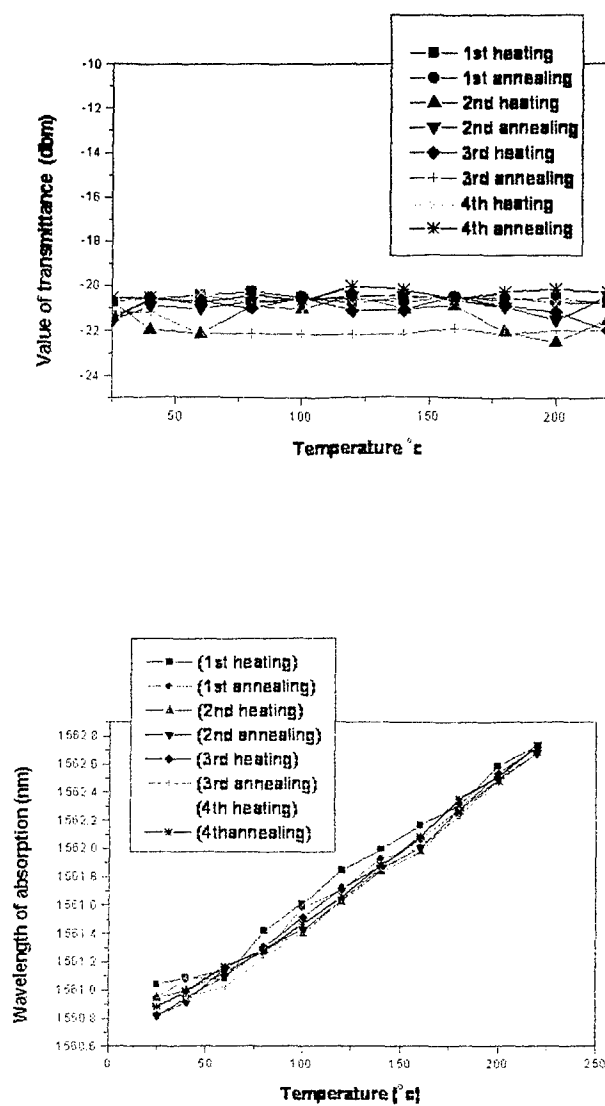


Figure 5. The spectrum variation of  $D_2$  loaded FBG in thermal annealing. It is clearly shown that the  $D_2$  loaded FBG has better spectrum stability than  $H_2$  loaded FBG. The Bragg reflection spectrum of the  $D_2$  loaded FBG is almost reversible in thermal annealing.